A new limit on heavy ion luminosity at the LHC

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The cross sections for electromagnetic processes at heavy ion colliders are very large[1], up to 33,000 barns for e^+e^- production at RHIC, rising to 200,000 barns at the LHC! These processes can impose significant limits on accelerator parameters.

Electron capture, where an e^+e^- pair is produced with the electron bound to one of the ions will limit the luminosity achievable with heavy ions at the LHC. The cross section for capture is large, with calculations predicting 45 barns for gold at RHIC, rising to 102 barns with lead at the LHC. Extrapolations from lower energy measurements predict cross sections two times larger[2]. The lower cross sections corresponds to 100,000 interactions per second with lead at the LHC, at a luminosity of $10^{27}/\mathrm{cm}^2/\mathrm{s}$. The beam power is 10 watts. This energy is deposited in the accelerator magnets, causing local heating.

Electron capture changes $^{82+}$Pb to $^{81+}$Pb, leaving the momentum unchanged. The magnetic rigidity increases by $1/Z$, far above the acceptance of the LHC magnetic lattice. The reaction creates a collimated beams of altered rigidity ions which will separate from the uninteracted beam and strike the beampipe downstream of each interaction point. A geometric extrapolation finds an impact point 194 meters downstream for lead (and closer to the interaction point for lighter nuclei). The beam energy is deposited over a target region with a length that depends on the beam divergence, magnetic optics, and size of the produced hadronic shower. For lead at the LHC, the dispersion gives a spreading of 0.9 meters, which is combined with a typical hadronic shower length of 0.9 meters (both are 1σ).

The beam power deposition will be about 2.65 W/m with lead. With niobium, the power is slightly higher, 3.2 W/m. This far exceeds the total heating loads used in designing the LHC, 2.5 W for a 9.7 meter long dipole. Heating due to beam effects (mostly synchrotron radiation, image currents and inelastic nuclear scattering) is expected to be 1.4 W/m, of which only 0.2 W/m will leak past a screen inside the beampipe. At best, the electron-capture energy deposition will strain the available cooling capacity.

A deposition of about 8 Watts/meter will induce a local magnet quench. Newer calculations with an improved modelling of the magnetic optics predict that, if the extrapolated cross section is correct, magnet quenching will limit the luminosity achievable with lead and niobium beams at the LHC[4].

References

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